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Landscape Implications of Contemporary Abandonment of Extensive Sheep Grazing in a Globally Important Agricultural Heritage System

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Abstract: In Southern Europe, the abandonment of the traditional transhumant system where sheep graze lowland areas during winter and distant mountain systems during summer has led to an important cultural loss and still poorly understood ecological consequences. We investigate the landscape-scale implications of contemporary sheep grazing patterns in a Globally Important Agricultural Heritage System (GIAHS). Our analysis showed a heterogeneous use of mountain grazing areas between 1990 and 2020. The areas most used by sheep had more abundance of pasture, fewer forests, and structurally different landscapes than those that had been fully abandoned by sheep. Likewise, we have detected decreasing trends in landscape diversity in those areas not used by sheep over the study period, whereas landscape heterogeneity is maintained in those areas grazed by sheep. Our study constitutes an original analysis of landscape patterns and shifts in relation to extensive sheep grazing by using novel approaches that combine interviews, updated satellite time series, and state-of-the-art landscape analysis techniques. Likewise, our results constitute a benchmark as they inform on the importance of preserving extensive sheep grazing if we aim to maintain the cultural heritage, and traditional diverse landscape and the semi-natural grasslands in the Mountains of León.

Keywords: Mountains of León; transhumant sheep; Landsat; landscape diversity; land cover

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1. Introduction

Since the middle of the 20th century, many European regions have been experiencing an intense rural exodus to urban areas [1,2]. This demographic change, added to the modern lifestyle and low profitability of farming practices in some zones, has led to the abandonment or marginalization of many regions from agricultural and pastoral use [1,3]. It has been observed that the most affected areas had been the small and extensive farming systems that dominate mountain regions, a decline often attributed to their remoteness, reduced competitiveness as consequence of physical limits on technical and structural adaptations, as well as to the adversity of mountain people to change due to age and deep-rooted tradition [3]. As mountain regions are abandoned, traditional landscape management unavoidably is, which has important social, cultural, and even environmental consequences by compromising the persistence of semi-natural managed habitats and landscapes [2,4].

A paradigmatic case of rural abandonment in Europe are the mountain regions in Spain [1]. There, livestock grazing is the dominant land use [5] that has played a crucial role in people's livelihoods for millennia [6] to the point that seasonal use by livestock in the Cantabrian Mountains has been dated since around 6000 BP, with proofs of extensive burning as a landscape management practice associated to pastoralism [7,8]. This seasonal use of resources, which has been maintained up to the present, consists basically in the use of elevated mountain areas during the summer and the wintering of livestock in lowlands with a more benevolent climate, exploiting the complementary pasture productivity throughout the year [7,9–11]. This pastoralist system is called transhumance, with two differentiated types: (I) transhumance *sensu stricto*, when there is a long-distance migration, and (II) transtermitance, when there is a short-distance migration [9,11].

The relevance of the transhumant system over time has given rise to the appearance of livestock breeds, such as the Merino breed, which is a highly appreciated sheep for its wool, and the traditional breed that used mountain pasturelands in Spain the last centuries; to legal regulations of transhumance since the s. VI, and more intensely since the XII century; to a network of livestock roads; to create a cultural context; and to the maintenance of ecosystem multifunctionality by sheep in the mountain pasturelands, including the conservation of productivity, diversity of habitats, ecosystem services, biological richness, and landscape structure [9,12–14]. Some authors [15–17] attribute to these periodic livestock movements and the successive occupation of different territories the maintenance of associated fauna in the same areas, such as *Neophron percnopterus*, *Aegypius monachus*, and *Gyps fulvus*, which benefits from the death of any animals along the way. They, therefore, underline the importance of such extensive pasture systems in the conservation of avian scavengers as source of carrion [16,17].

In line with these values, the Food and Agriculture Organization of the United States (FAO) declared, in 2022, the Agro-silvo-pastoral system Mountains of León (the primary receptor region of transhumant sheep during summer in Spain) as a Globally Important Agricultural Heritage Systems (GIAHS) [18]. Among the main recognitions, FAO [18] states that the Mountains of León sustains local animal varieties, a unique biodiversity, and a cultural diversity that is reflected in high-value landscapes that include an exceptional agroforestry and livestock cultural heritage. The present rural exodus and socio-cultural change are declining the transhumant practice and the extensive grazing of mountain grasslands by sheep flocks since the middle of the last century [9,14,19], which still has poorly understood consequences that might undermine the values that have contributed to the GIAHS declaration.

One of the major changes that the Mountains of León has experienced in the last decades is the advancement of the secondary succession via shrub encroachment and the colonization of trees of ancient farmland and grazing areas [20,21]. These processes lead to significant changes in the structure of the landscape, mainly with a clear homogenization [22]. The links between this landscape change with the agricultural abandonment and decline of extensive grazing seem obvious [20–23], but there is scarce empirical evidence in the Mountains of León [24]. Nowadays, the most efficient way to analyze landscape patterns in relation to ecological factors is probably using orthophotos and satellite imagery. Although orthophotos are not available for many years, the Landsat satellite mission offers images since 1972, mostly at 30 m spatial resolution every 16 days. Likewise, recent advances in remote sensing allow the accurate analysis of fine-grained landscapes, such as those in the Mountains of León, by taking advantage of spectral unmixing techniques [25]. The implementation of these methods enables analyses accounting for the composition at the sub-pixel level (i.e., using fraction images) [26] and landscape analysis based on classical hard-classifications (i.e., using categorical images), allowing the calculation of traditional class and landscape metrics [27].

In this context, our goal is to analyze the implications of contemporary sheep grazing patterns on the landscape structure of a recently declared GIAHS. Specifically, we aim to identify (I) the heterogeneous degrees of use by sheep over time in traditional mountain grazing areas in the Mountains of León (1990–2020), as well as to analyze there the influence of sheep flocks on (II) land cover classes, (III) landscape diversity, and (IV) landscape structure of grassland patches by means of remote sensing methods. We hypothesize that the Mountains of León is a heterogeneous mosaic in terms of sheep grazing abandonment, with many areas abandoned because of the social, cultural, and economic context exposed above [1–4], and some other areas still grazed by sheep. We also expect extensive sheep grazing to affect the land cover classes, mainly by maintaining pasture areas and limiting shrub encroachment [20,21], which would contribute to landscape diversity by maintaining the even distribution of land cover classes in a landscape where shrublands usually dominate [20–22]. In the same way, we hypothesize that the areas that continue to be extensively grazed by sheep exhibit a different structure in terms of grassland core area and distance between grassland patches.

The novelty of the study relies not only in the research questions, but also in the use of long-time series of satellite imagery up to near present and the exploitation of state-of-the-art methods for imagery and landscape analysis. Moreover, the information obtained will provide updated information on sheep grazing in traditional grazing areas of the GIAHS Mountains of León, and novel evidence of how land use changes can modify the landscape structures in areas historically characterized by a high degree of landscape heterogeneity. This knowledge is key for policy and socio-economic decisions to conserve cultural heritage sites relevant at the international level.

2. Materials and Methods

2.1. Study Sites

Our study area was in the Mountains of León (southwestern Cantabrian Mountains), which is one of the regions in the Iberian Peninsula with more mountain pasture areas used by transhumant merino sheep. The pasture areas traditionally used by transhumant merino sheep are locally known as "puertos pirenaicos" (pyrenean passes) or "puertos de merinas" (merino passes), depending on the geographical region, historical and current ownership, and administration. Here, we refer to all of them as merino passes. The merino passes have historically received transhumant merino sheep during summer, after wintering in lowlands far south, usually in Extremadura. Weather and productivity seasonality only allows full exploitation of merino passes by livestock from June to September [12]. Nowadays, shorter displacements have become predominant, and many merino passes are currently rented to livestock farmers for cattle and horses. We consider that the Mountains of León constitutes an exemplar region to address our objectives in view of (I) the traditional use by merino sheep during centuries [9], (II) the current miscellaneous of merino passes situations in terms of land use, and (III) the recognized international relevance of this region by FAO as GIAHS [18].

Specifically, we had selected 104 grazing areas (merino passes) (Figure 1) distributed across the Mountains of León. These merino passes are property of the village councils or municipalities that rent them to animal breeders and managed by the Territorial Section for the Environment of the Junta de Castilla y León. They are characterized by a mountainous orography resulting in elevations ranging from 1100 to 2400 m. The climate is temperate in most of the areas (Köppen classification Csb) and continental in the mountain tops (Köppen classification Dsb, Dsc and Dfc), all with a Mediterranean influence to some extent, with the summer months being the hottest and driest. The mean annual temperatures range between 5 and 11 °C, and annual precipitations between 1000 and 1500 mm. In the western extreme of this region, the predominant lithology is siliceous, whereas, in the central and eastern parts, there is an alternation of siliceous and calcareous lithologies across the landscape with scarcely developed soils in steep slopes. The orography, climate, and soil largely determine the vegetation which, within each merino pass, is a mosaic usually composed of rocks and bare soil, pasturelands, shrublands dominated by species from the genera *Erica*, *Cytisus*, or *Genista*, and arboreal vegetation, mainly oak (*Quercus petraea* and *Q. pyrenaica*) or beech (*Fagus sylvatica*) forests, which are more abundant in the eastern merino passes.

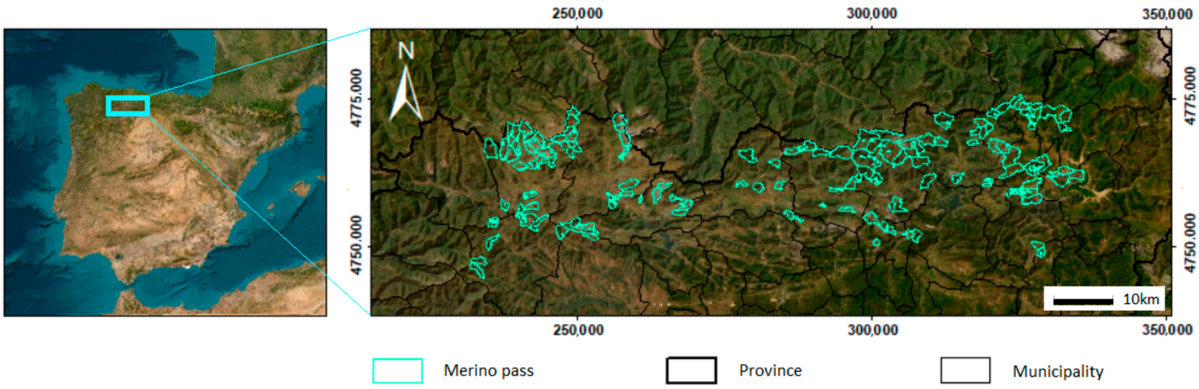

Figure 1. Location of the study region within the Iberian Peninsula (map on the **left**), and location of the 126 merino passes initially selected for the study (map on the **right**). Reference system: ETRS1989 UTM Zone 30N.

2.2. Materials

To address this study, we had used the materials shown in Figure 2. First, we acquired and pre-processed one annual Landsat scene between 1990 and 2020. Second, the available orthophotos since 1983 were used as ground truth. Third, the territorial limits of 126 merino passes were obtained from the official cartography. Lastly, we interviewed landowners and sheep keepers to discover the degree of sheep use of each pass over the study period.

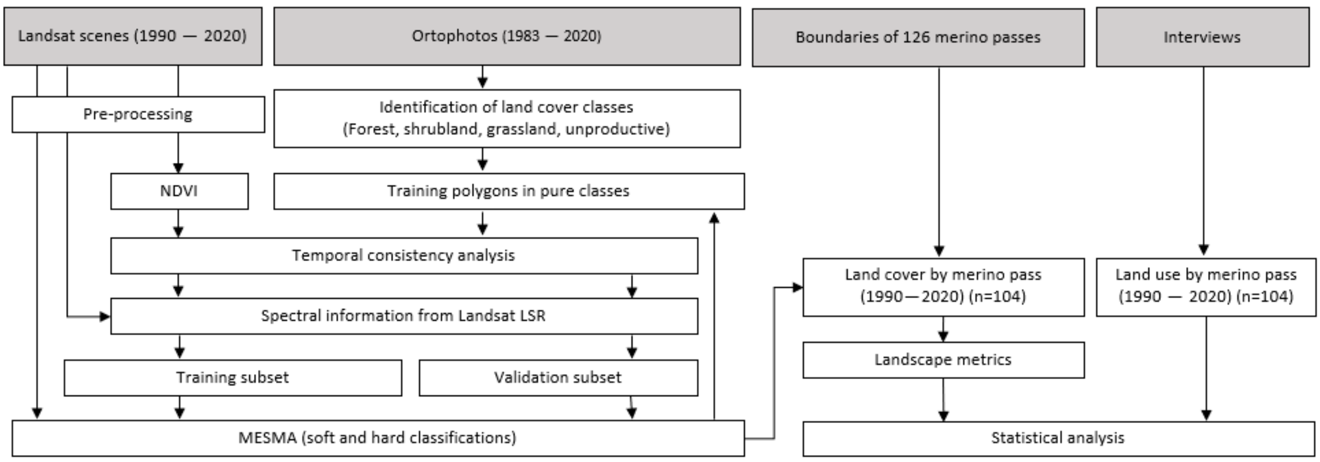

Figure 2. Materials used in this study (shaded in grey) and methodology flowchart (shaded in grey and green). NDVI—Normalized Difference Vegetation Index; MESMA—Multiple Endmember Spectral Mixture Analysis.

2.2.1. Satellite Imagery and Orthophotography

To obtain time series of high-quality surface reflectivity images, (I) we selected proper raw images, and (II) we pre-processed them mainly by performing a harmonization of reflectivity values between the different sensors and a topographic correction.

For the entire time series (1990–2020), a multispectral image of each year was chosen and downloaded from the Earth Explorer server of the United States Geological Survey https://earthexplorer.usgs.gov/ (accessed on 31 December 2022) with a preference for the summer images (June–September), since they present high solar elevation angles and less snow cover, always selecting the one with the least cloud cover possible. Thus, a database composed of 30 multispectral images from the Landsat 5 (TM sensor), Landsat 7 (ETM+ sensor), and Landsat 8 (OLI sensor) satellites was created. The acquired images were Landsat collection 1 Level-2 scenes, which are radiometrically and geometrically corrected, georeferenced to a Universal Transversal Mercator (UTM) projection, and corrected for atmospheric effects with the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) algorithm for TM and ETM+ images, and with the Land Surface Reflectance Code (LaSRC) for OLI scenes. Only the 6 bands of the optical region (blue, green, red, near infrared, and two shortwave infrared bands) were used in this study.

The pre-processing of the acquired images consisted of a harmonization of OLI-derived scenes to reflectivity values comparable to the images from the TM and ETM+ sensors using the equations obtained by Roy et al. [28]. Likewise, the ETM+ sensor images, with the error coming from the Scan Line Corrector (in our case, the images corresponding to the years 2006 and 2012), were corrected by a Delaunay interpolation. A topographic correction was applied to the set of atmospherically corrected images to eliminate the effect of topographic shadows by applying the cosine algorithm proposed by Teillet in 1982 [29]. We selected this topographic correction method as it is independent of the reflectivity values of the image. For the application of this algorithm, a digital elevation model of 25 m spatial resolution calculated from the BTN25 of the National Center for Geographic Information https://centrodedescargas.cnig.es (accessed on 31 December 2022) was used. Finally, outliers were eliminated from the images, i.e., with reflectivity values lower than 0% or higher than 100%. In this way, a pre-processed Landsat image database of Land Surface Reflectance (LSR) suitable for landscape classifications was built.

As reference data (ground truth), we used aerial orthophotographs (pixel size $\leq$ 50 cm) covering the entire study period. To inspect the landscape for the oldest years, we compared images 1983 (inter-ministerial flight), images from 2001–2002 (SIGPAC flight), and the orthophotos from 2004, 2006, 2008, 2011, 2014, 2017, and 2020 (Plan Nacional de Ortofotografía Aérea-PNOA). In view of the temporal gaps without reference data, an analysis of the spectral consistency of Landsat images was conducted to guarantee the quality of training and validation areas (see Section 2.3.1 Land cover classifications).

2.2.2. Merino Passes and Interviews

The boundaries of 126 merino passes in the Mountains of León were obtained from the official cartography available in the Territorial Section for the Environment of the Junta de Castilla y León (regional administration) [12].

To obtain information on the use of the merino passes by sheep flocks in the period 1990–2020, interviews were conducted with the land managers of each merino pass which, in most cases, were members of the village councils and of the municipal entities. When no response was obtained from them, surveys were carried out with the local farmers. The surveys revealed the complexity of obtaining quantitative grazing pressure data by sheep flocks, because of the lack of information related to the temporal use (i.e., how many days during the year), the number of heads of sheep extensively grazing, and the heterogeneous pressure over space within each merino pass. Thus, we decided to perform a semi-quantitative classification of the merino passes in function of the temporal use by sheep. To do that, we asked the interviewees how many years during the period 1990–2020 the mountain pass had been grazed by sheep during summer (i.e., by transhumant sheep, including transtermitant sheep. Note that no flock of sheep spends the winter in the merino passes). With this information, we classified the merino passes into (I) not used (any year has been grazed by sheep), (I) lowly used ($\leq$25% of the years grazed by sheep), (III) moderately used (between >25% and $\leq$75% of the years grazed by sheep), and (IV) highly used (>75% of the years used by sheep). We obtained the above information for 104 of the 126 merino passes initially selected for this study (i.e., 104 interviews were successfully accomplished, one for each of the finally selected merino pass, and a total of 55 interviewees participated. Note that one entity or farmer can manage or use more than one merino pass). The 22 merino passes without land use information were removed for further analyses.

2.3. Methods

2.3.1. Land Cover Classifications

To perform the land cover classifications, we (I) identified the main land cover classes in the study area, (II) defined regions of interest (ROIs) to train and validate the classifications, (III) we obtained the fraction images (soft classification) and the dominant class within each pixel (hard classification), and (IV) we validated the classifications. Each step is described in each of the following paragraphs.

We identified the main land cover categories in the study areas based on the classes used in previous studies in the Cantabrian Mountains [22,25,26] and based on a visual inspection of orthophotographs of the merino passes. The following categories were differentiated: forest (areas predominantly covered by tree species), shrubland (including areas predominantly covered by shrub and sub-shrub species), grassland (including pastures, mowing meadows), and unproductive areas (areas devoid of vegetation, mainly rock, bare ground, and burned areas).

In each of the land cover categories, ROIs were delimited using the aerial orthophotos as a reference. The ROIs were used to obtain the spectral signatures of each land cover category from the Landsat images, which are necessary for the spectral unmixing techniques to obtain fraction images of each category, making possible the subsequent classification of each pixel of the image. The size of each ROI was set at 90 m $\times$ 90 m to ensure that it includes at least one complete Landsat pixel; the minimum separation between different ROIs was set at 300 m, which corresponds to ten Landsat pixels; and a minimum distance of 30 m was set from the ROI of a given category with respect to areas with different land cover, thus ensuring that the pixel values included within the ROI are not affected by other different land cover categories (i.e., are pure pixels). In total, 220 ROIs were established in homogeneous areas that presented the same land use throughout the time series. To ensure that the occupancy category assigned to each of the ROIs remained invariant over the study time (1990–2020), all the available aerial orthophotographs were inspected. To ensure that the land cover in the ROIs did not change, even in the periods where there was no orthophotography, a sensitivity or consistency analysis was performed based on the Normalized Difference Vegetation Index (NDVI) values of each of the Landsat images of the 1990–2020 time series. This analysis consisted of the extraction of NDVI values for each ROI and the application of the Grubbs test for the detection and elimination of outliers. Specifically, outliers were eliminated for each land cover category (forest, shrubland, grassland, and unproductive) within each year (outlier in the image) and over time (outlier in the time series). After performing these analyses, the set of ROIs was reduced to 173, whose NDVI values by category are shown in Figure 3. NDVI values were highest for forest and intermediate for shrubland and for grassland, which showed greater variability. Unproductive areas presented the lowest NDVI. Likewise, for the 173 ROIs, the spectral signatures corresponding to each of the Landsat images were extracted (Figure 3), which allowed us to analyze the separability of the different categories of land occupation and, therefore, their suitability for landscape classifications. The results showed minimum Jeffries-Matusita separability values of 1.38 between grassland and shrubland categories; 1.78 between forest and shrubland; and values higher than 1.88 for the rest of the pairs. The Jeffries-Matusita parameter can range from 0 (pairs of identical spectral signatures) to 2 (completely different spectral signatures), so the values obtained in this study indicate that the established occupancy categories are different at the spectral level, allowing landscape classifications with low levels of error.

The set of 173 ROIs was divided into two subsets: a subset of 87 ROIs to obtain the spectral signatures needed for fractional imaging and subsequent image classification (training), and a subset of 86 ROIs to perform the validations of the classifications. With the training subset, 31 annual spectral libraries were composed of 348 signatures each (4 signatures per ROI). Each of the libraries was subjected to the IES (Iterative Endmember Selection) process [30] for the selection of optimal groups of spectral signatures. The optimized annual libraries were comprised between 15 and 25 signatures and achieved mean internal Kappa values above 0.90 for the classification of the four land cover classes. Spectral libraries were obtained and optimized using the Spectral Library Tool plug-in [31] in QGis [32]. Once the optimized libraries were obtained, the MESMA (Multiple Endmember Spectral Mixture Analysis) method was applied to obtain fractional images of the four land cover classes (forest, shrubland, grassland, and unproductive). Subsequently, a hard classification was performed by assigning to each pixel the category with the predominant fraction. Landscape classifications using MESMA were performed with the MESMA plug-in [33] implemented in QGis [32].

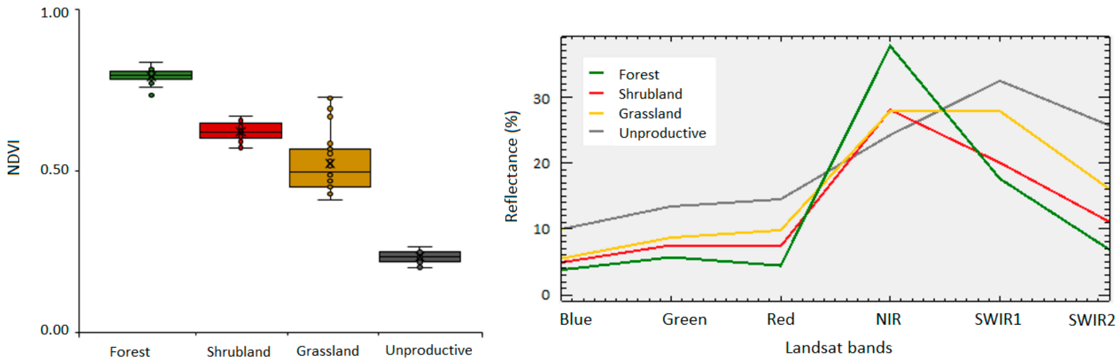

Figure 3. Spectral properties of the defined land cover classes (wooded, shrubland, grassland, and unproductive). Left: boxplot showing the medians and interquartile ranges for the different classes calculated with the annual mean values for the 1990–2020 series (n = 31). Right: spectral signatures corresponding to the ROI polygons from the Landsat 5 image of 10 August 1990.

The hard classifications of Landsat images from 1990 to 2020 performed with MESMA were validated using confusion matrices, which allowed calculating the overall accuracy of the classifications, the producer's accuracy, and the user's accuracy. The matrices were performed using as ground truth the 86 ROIs destined to the validations, which meant a total of 344 pixels per year.

2.3.2. Landscape Variables

Fraction images derived from MESMA were used to calculate the percentage of landscape occupied by each land cover class in each merino pass.

Hard classifications were used to calculate landscape metrics related to the overall landscape structure: the Shannon [34] and Simpson diversity indices [35]. We also used these classifications to calculate the Euclidean distance between grassland patches and the grassland core area, understanding core areas as those further than 60 m from the grassland border. Both metrics are indicative of the structure of pasture patches in the landscape. Diversity indices and grassland metrics were calculated with Fragstats [27].

The temporal evolution of these variables was represented by fitting generalized additive models (GAM), which allow us to visualize and interpret the evolution of each of the variables over time, whether they are monotonic or not, and their confidence intervals. In addition, for each variable, the significance of the global trend (1990–2020) was calculated using the Mann-Kendall test, and the global annual change was quantified using the Theil-Sen slope estimator. This estimator was chosen because of its high robustness even in the presence of anomalous, asymmetric, and heteroscedastic values. These statistical analyses were performed with R [36] using the packages openair [37] and trend [38].

3. Results

3.1. Use of Merino Passes by Sheep

The classification of the merino passes according to the years of use by sheep (Figure 4) showed that the passes with the highest degree of use by sheep over time are those in the western part of the study area. In the eastern part of the study area, there was a predominance of passes that have not been used by sheep during the entire period (1990–2020).

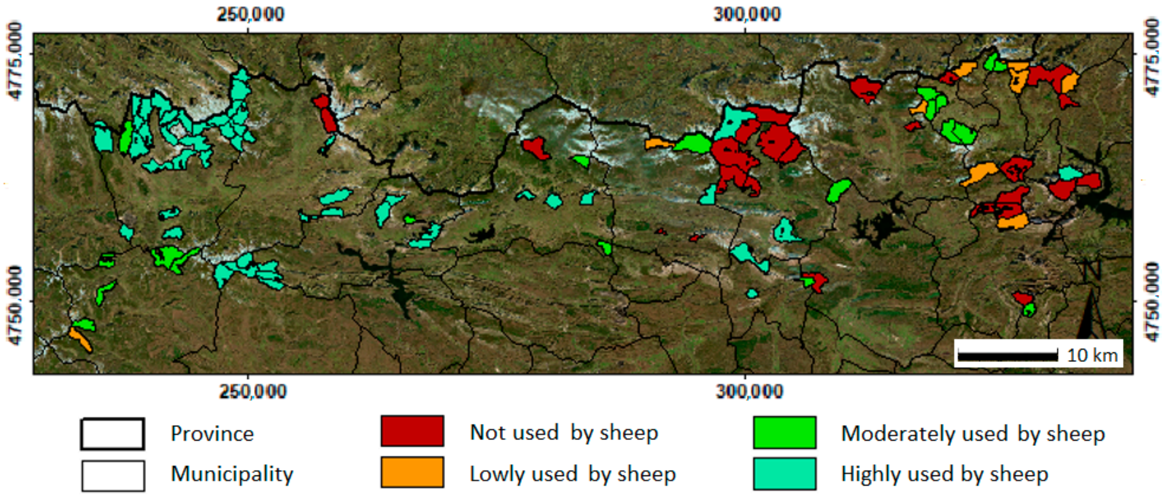

Figure 4. Map showing the classification of merino passes according to their time of use by sheep during the period 1990–2020, determined by the number of years they have received sheep flocks. Reference system: ETRS1989 UTM Zone 30N.

3.2. Landscape Shifts in Relation to the Use by Merino Sheep

The confusion matrices of the MESMA classifications resulted in overall accuracy values ranging from 73.45% to 84.61% (79.24% ± 0.55; mean ± standard error), while the producer's accuracy values (informing on the error of omission) and user's accuracy (informing on the commission errors) were 83.15% ± 1.63 and 76.93% ± 1.23, respectively. Annual values of the overall accuracy, producer's accuracy, and user's accuracy are shown in Figure 5.

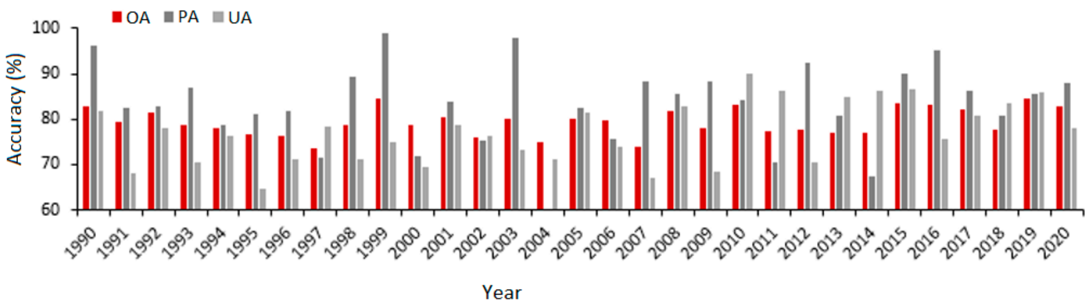

Figure 5. Accuracy of the hard classifications performed with Landsat scenes between 1990 and 2020. OA—overall accuracy; PA—producer's accuracy; UA—user's accuracy.

Figure 6 shows that the merino passes with the longest time of use (moderately and highly used) are those with the lowest forest cover, although the changes over time for this variable are not significant (Table A1). Similar shrub cover was identified in all merino passes regardless of the time of use by sheep (Figure 1), with no significant changes over time (Table A1). Grassland was the dominant cover in merino passes, with the highest values in those used by sheep most of the time (Figure 6). Although a positive trend of grassland cover is observed between 2010 and 2020 in the highly used passes (Figure 6), trends for the period 1990–2020 were not significant (Table A1). In relation to the unproductive cover, there was a decreasing significant trend in all the situations, the most intense being detected for the highly used passes (−0.21% year^{-1}).

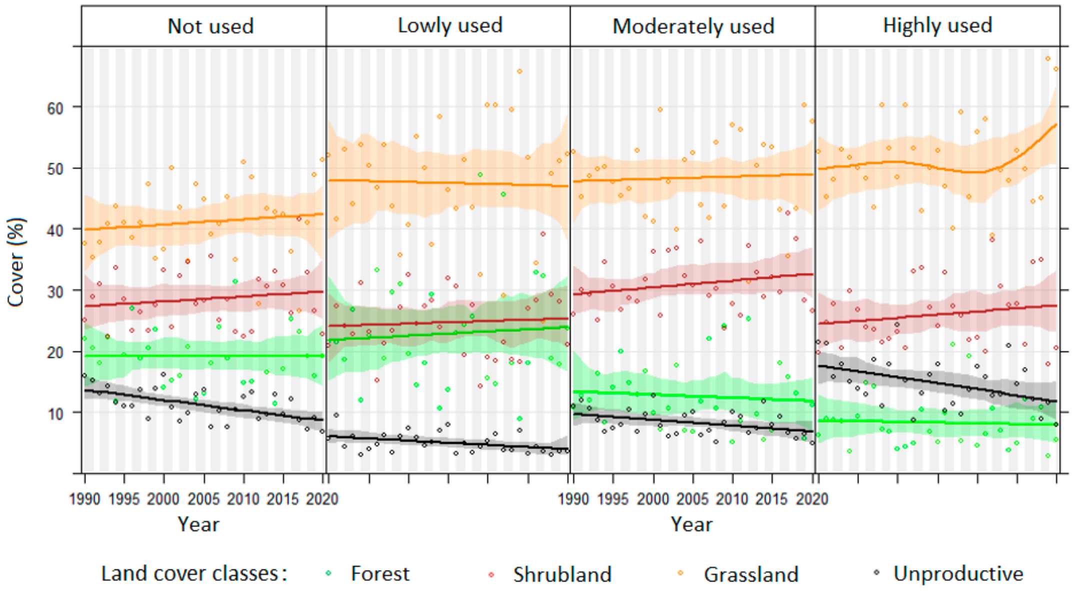

Figure 6. Temporal evolution (1990–2020) of the cover of the different land cover classes in the merino passes grouped according to the time of use by sheep (not used, lowly used, moderately used, and highly used). The dots indicate the mean values for each year, the line predicted values by generalized additive models, and the shading of the 95% confidence interval.

The Shannon and Simpson diversity of land cover classes was similar in the merino passes according to sheep use, although the passes highly used by sheep showed slightly lower values (Figure 7; Table A2). In relation to the temporal evolution of diversity, we observed that merino passes not used by sheep showed declines in diversity, while passes with some degree of sheep utilization did not show changes over time. This suggests that sheep grazing could have a relevant role in the conservation of diversity at the landscape scale.

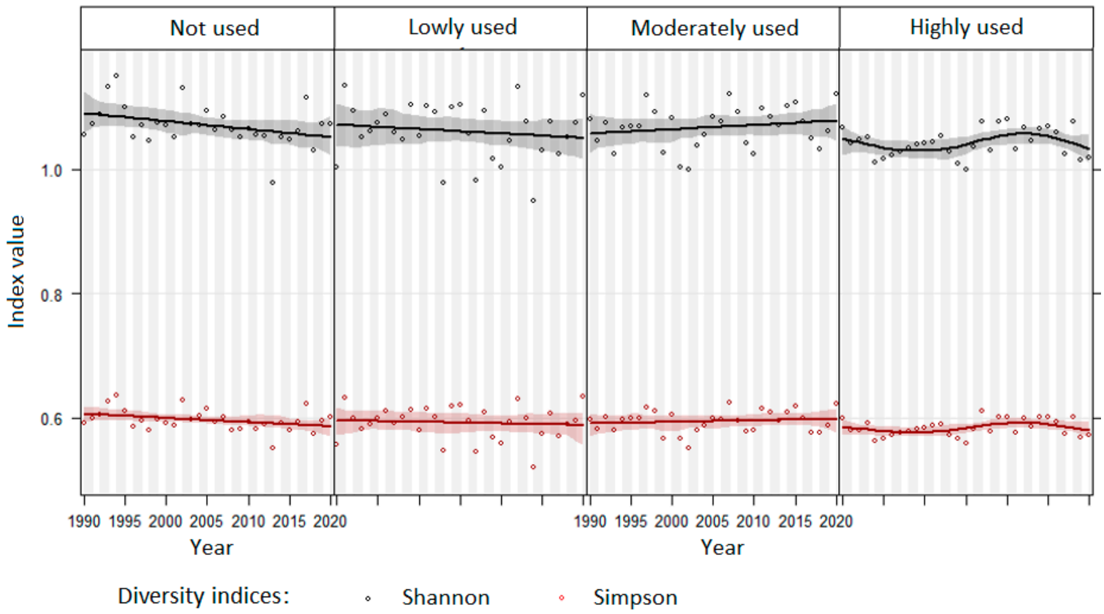

Figure 7. Temporal evolution (1990–2020) of landscape diversity estimated with Shannon and Simpson's diversity indices in the merino passes grouped according to the time of use by sheep (not used, lowly used, moderately used, and highly used). The dots indicate the mean diversity values for each year, the lines predicted values by generalized additive models, and the shading of the 95% confidence intervals.

The merino passes most used by sheep (moderate and highly) had lower Euclidean distances among grassland patches and more core area (Figure 8), but the temporal trend over the 31-year study period did not show significant differences (Table A3), except in the situation of not use that showed a clear increase over time.

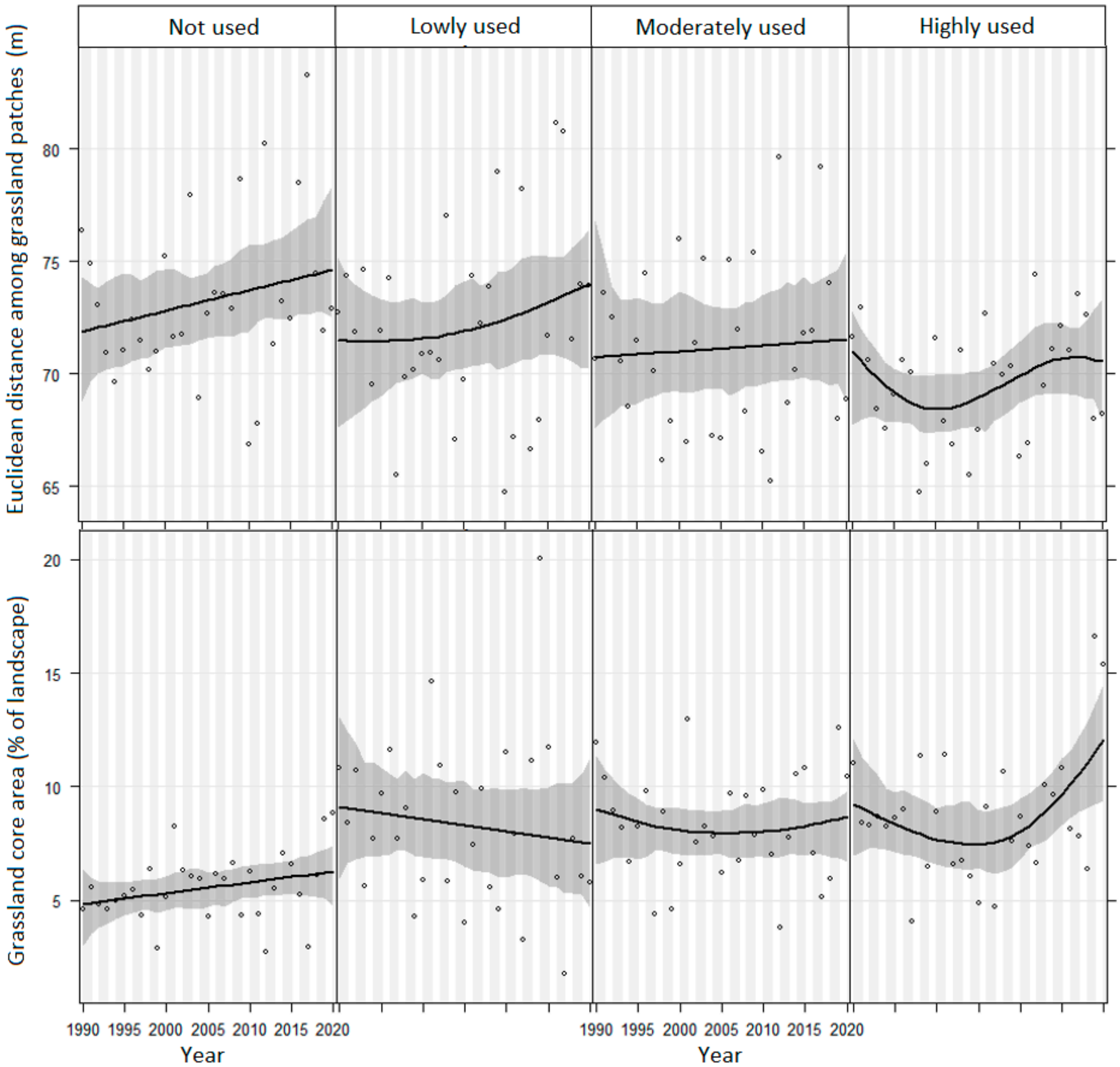

Figure 8. Temporal evolution (1990–2020) of the mean Euclidean distance between grazing patches (m) and of the percentage of the landscape that is grassland core area (%) in the merino passes grouped according to the time of use by sheep (not used, lowly used, moderately used, and highly used). The dots indicate the mean values for each year, the lines predicted values by generalized additive models, and the shading of the 95% confidence intervals.

4. Discussion

Our work provides evidence supporting the context of change in GIAHS of the Mountains of León, particularly in relation to transhumant sheep grazing and the potential consequences of this change in the landscape composition and structure.

This study analyzing a long time (31 years) confirms the abandonment of the traditional use of the merino passes, as our interviews revealed that 24 out of 104 study sites were not grazed by sheep in any year of the 31 studied years. This change is particularly relevant as the selected mountain passes for this study are among the most appreciated for this livestock (administratively called puertos pirenaicos and auctioned with priority for sheep herders) within around 400 mountain pasture areas in the Mountains of León traditionally used for sheep grazing [12]. This information supplements the vast work of Rodríguez Pascual [9], who described the history of transhumance in Spain, since the first legal evidence in the VI century to the transhumant decay in the last decades of the XX century. The change observed during the last decades of the XX century supposed a shift from transhumance *sensu stricto* (long distance) to transtermitance, as well as a shift from merino sheep to cattle and horses. The change in the composition of the livestock population leads to changes at the landscape level, since sheep make use of a whole range of pasture and nutrient resources that no other type of livestock would make use of [9,24].

Reflected in numbers, Rodríguez Pascual [9] indicates that 136,880 transhumant merino sheep grazed in the merino passes in the Mountains of León in the 1950s, whereas only 86,324 transtermitant merino used the passes in 1990, the long-distance transhumance being largely reduced on that date (around 10,000 heads) [39]. In 2012, García-Llamas et al. [21] reported further declines to 37,922 sheep, whereas cattle increased from 3569 to 9996 heads between 1990 and 2012.

Our findings also revealed that this context of change may lead to shifts at the landscape level. Thus, comparing the mean values of the different land cover classes among merino passes with different degree of use by merino sheep, we found that those sites with the highest use by sheep were those with the lowest tree cover, which may be related to the location of these passes in the western region of the Mountains of León, which presents, in general, less fractional cover of forest [25] as well as to the effects of grazing [40]. The sites most used by sheep had a higher grassland cover than the ones not used or scarcely used, which can be attributed to the fact that grazing by sheep favors the maintenance of grazing areas, either directly through herbivory or indirectly through forest management related to the creation of open areas to favor grazing. In relation to the first, it is well known that sheep grazing sustains different plant communities than cattle, limiting the development of shrubs [8,9]. However, the absence of significant temporal trends difficult the establishment of clear causal-effect relationships, as there is also the possibility that it is those passes with the greatest amount of pasture that continue to be selected by the shepherds to be used by the sheep flocks, as suggested by Rivero Ordaz et al. [24]. Similarly, the sites most used by sheep had lower Euclidean distances among grassland patches and more core area, but the temporal evolution over our 31-year study period is not clearly linked to sheep use.

The scarce forest and the dominance of grasslands in the merino passes most used by sheep results in a low equitability among land cover classes, thus resulting in less diversity of landscape classes in these sites than in those not used or scarcely used by sheep. However, we also found that the landscape diversity of the sites grazed by sheep is maintained over time, while those not used become less diverse after at least 31 years of abandonment. This agrees with the results found by Rivero Ordaz et al. [24], who reported a positive effect of sheep grazing on landscape diversity trends when comparing 10 grazed merino passes with 10 non-grazed by sheep over 19 years. In this context, MacDonald et al. [3] indicated that abandonment of rural mountain regions in Europe might lead to increased landscape diversity, but to decreases over the long term as consequence of landscape homogenization.

This study provides empirical evidence based on field surveys and remote sensing data that the extensive sheep grazing in the Mountains of León still exists, but at a much smaller scale than in former times, and informs on the importance of sheep grazing in shaping the landscape composition and structure. A window of opportunity is open for future research to better identify causal-effect relationships by considering the multiple factors that might affect sheep keeper preferences for merino passes, as well as to control for other factors that might affect landscape evolution. Among them, we encourage to consider landscape fires, silvo-pastoral and fuel management actions or reforestations, as well as the herbivory pressure of other animals apart from sheep (e.g., cattle, horses, and goats).

Likewise, we highlight that knowledge on the role of extensive sheep grazing, and particularly transhumance, in the landscapes of the Mountains of León is necessary to apply the most adequate management policies as well as to conserve the new international recognition of this mountain landscapes where humans and nature have coexisted for millennia [7,8]. In this sense, the detected land use situation of the merino passes, as well as the links between extensive sheep grazing, landscape diversity, and grassland structure found in our study, indicate that, if we aim to maintain all the cultural heritage, the semi-natural grasslands, and the diverse landscapes in the Cantabrian Mountains, political and management decisions should be focused on preserving extensive sheep grazing.

5. Conclusions

Our study updates the use of the merino passes by sheep in the Mountains of León. In this sense, we reveal that sheep grazing was null for the period 1990–2020 in 24 out of 104 analyzed areas that are among the most appreciated for merino sheep. The past abandonment of less appreciated grazing areas, together with our results, confirm the contemporary trend of abandonment of extensive grazing in the Mountains of León.

The application of spectral unmixing techniques to Landsat time series (1990–2020) evidenced potential landscape implications of the abandonment of extensive sheep grazing. In general, the most grazed merino passes exhibited less forest and less shrubland cover and more grassland cover. Likewise, grassland patches were closer among them and larger in the grazed areas than in those fully abandoned or less used. The abandonment of extensive sheep grazing also leads to different temporal trends, particularly for the diversity of land cover classes, which significantly decreased in the areas not grazed by sheep.

Our findings are highly relevant as they inform on the ongoing cultural loss and landscape change in a GIAHS providing empirical evidence that links the abandonment of extensive sheep grazing to the loss of the traditional diverse landscape of the Mountains of León and to the decline of grasslands. Thus, we emphasize the importance of taking measures to preserve extensive sheep grazing as a key factor for the conservation of these elements that have contributed to the declaration as GIAHS.

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Appendix A

Table A1. Results of the trend analysis of the different types of land cover in the merino passes, differentiating degrees of utilization by sheep (not used, lowly used, moderately used, and highly used). The change column indicates the slope calculated with the Theil-Sen method (annual change for the variable of interest). p indicates the degree of significance according to the Mann-Kendall test.

	Not Used		Lowly Used		Moderately Used		Highly Used	
	Trend	p	**Trend**	p	**Trend**	p	**Trend**	p
Forest	−0.02	0.89	0.01	1.00	−0.10	0.41	−0.04	0.78
Shrubland	0.05	0.68	0.03	0.82	0.09	0.30	0.07	0.52
Grassland	0.12	0.28	−0.01	1.00	0.08	0.65	0.01	0.89
Unproductive	−0.16	0.00	−0.06	0.04	−0.10	0.01	−0.21	0.01

Table A2. Results of the trend analysis for the diversity of land cover classes calculated with Shannon and Simpson's diversity indices and differentiating the time of sheep utilization (not used, lowly used, moderately used, and highly used). The trend column indicates the slope calculated with the Theil-Sen method (annual change for the variable of interest). p indicates the degree of significance according to the Mann-Kendall test.

	Not Used		Lowly Used		Moderately Used		Highly Used	
	Trend	p	**Trend**	p	**Trend**	p	**Trend**	p
Shannon	−0.001	0.06	−0.001	0.50	0.001	0.23	0.000	0.38
Simpson	−0.001	0.08	0.000	0.89	0.000	0.63	0.000	0.29

Table A3. Results of the trend analysis for the change in the mean Euclidean distance between grazing patches (m), and of the percentage of the landscape that is grassland core area (%) column indicates the slope calculated with the Theil-Sen method (annual change for the variable of interest). p indicates the degree of significance according to the Mann-Kendall test.

	Not Used		Lowly Used		Moderately Used		Highly Used	
	Trend	p	**Trend**	p	**Trend**	p	**Trend**	p
Euclidean distance	0.07	0.21	0.07	0.54	0.01	0.92	0.03	0.50
Core area	0.06	0.07	−0.08	0.32	−0.02	0.79	0.03	0.63

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